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Ionospheric response at low latitudes on the local time variation of sudden commencement and the intensity of geomagnetic storms

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Abstract : The dependence of the ionospheric response on the time of occurrence of sudden commencement (SC) and the intensity of the geomagnetic storms have been investigated by considering the total electron content data for 68 SC-type geomagnetic storms at a low latitude station Palehua, [19 70°N, 157 2°W], during the period 1985-89 The ionospheric response was found to be influenced by the local time of SC The time delays associated with peak positive responses were short for day time SCs and long for night time SCs where as the opposite applies for negative responses The time delays were inversely proportional to the intensities of geomagnetic storms irrespective of their nature as positive or negative There was a positive correlation between the strength of ionospheric response and the intensity of the geomagnetic storms However, this study shows that the strength of both positive and negative storms decreases with increase in magnetic activity index A_p for very severe storms The results are discussed in the light of possible mechanisms which may contribute to the storm-associated ionospheric variations

Keywords : Ionospheric response, SC type geomagnetic storms.

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1. Introduction

The appreciable deviation of an ionospheric parameter from its monthly median average or otherwise typical behaviour is generally referred to as "ionospheric storm". Some of the storms have a sudden commencement (SC) which last one or two days after a solar chromospheric flare. Total electron content (TEC) is an important ionospheric parameter which is the measure of the total number of electrons in a vertical column of unit cross section extending from ground to the top of the ionosphere. Being weighted more than 90% by the F region peak ionization, TEC reflects most of the properties of the peak electron density. The total electron content data used in the present study were derived by Faraday rotation technique [1,2]. The polarization angle of a plane polarised radio wave rotates as it traverses the ionosphere by an amount which depends on the number of free electrons along the ray path. Measurement of the angle of rotation is known as Faraday rotation. Hence, it gives a direct measure of TEC along the line of path between the satellite transmitter and the ground receiving station. TEC analysis have direct application in communication links [3–5]. Some of the applications for which TEC data used are refraction correction, time delay correction and margins of allowance for amplitude fades. Models for TEC based on observational data have been developed which could be used for satellite tracking applications [6,7].

Although extensive studies have been conducted on the storm time ionosphere and total electron content (TEC) behaviour [8], a clear picture has yet to emerge for the TEC behaviour under disturbed conditions [9–11]. The storm variations of the electron content depend on the phases of a geomagnetic storm, location, season and local time of occurrence. Extensive studies on the morphology of ionospheric storms have been made using peak electron density (Nmax) and total electron content (TEC) data obtained through various experimental techniques and the current status of TEC and scintillation studies has been recently reviewed [12–14].

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A recent study has been conducted to describe the sequence of processes that result from the flow of energy from the magnetosphere to the upper atmosphere associated with geomagnetic storms with the help of numerical models [15]. The large scale morphology and physics of magnetic storm associated perturbations of the upper atmosphere have been recently summarised [16]. Also the evaluation of global scale equatorial and low latitude ionospheric disturbances in response to the weak-to-moderate disturbed conditions that marked the SUNDIAL/ATLAS 1 campaigns and the comparison of the results with the predictions from International Reference Ionosphere (IRI) and the Field Line Integrated Plasma Model (FLIP) were done [17].

The present study is designed to investigate the dependence of ionospheric storms on local time of occurrence, intensity, time delay for peak response at a low latitude station Palehua [19.70°N, 157.2°W] by considering TEC for 68 SC-type geomagnetic storms during 1985–89.

2. Data and analysis

Sudden commencement (SC) type geomagnetic storms that occurred during 1985–89 with daily magnetic activity index $A_p \geq 20$ on at least one day of the storm period are selected for the study. Additional criteria used in the selection of events are based on the conditions that the ionospheric response to individual events are to be isolated and that the pre-storm conditions should be quiet.

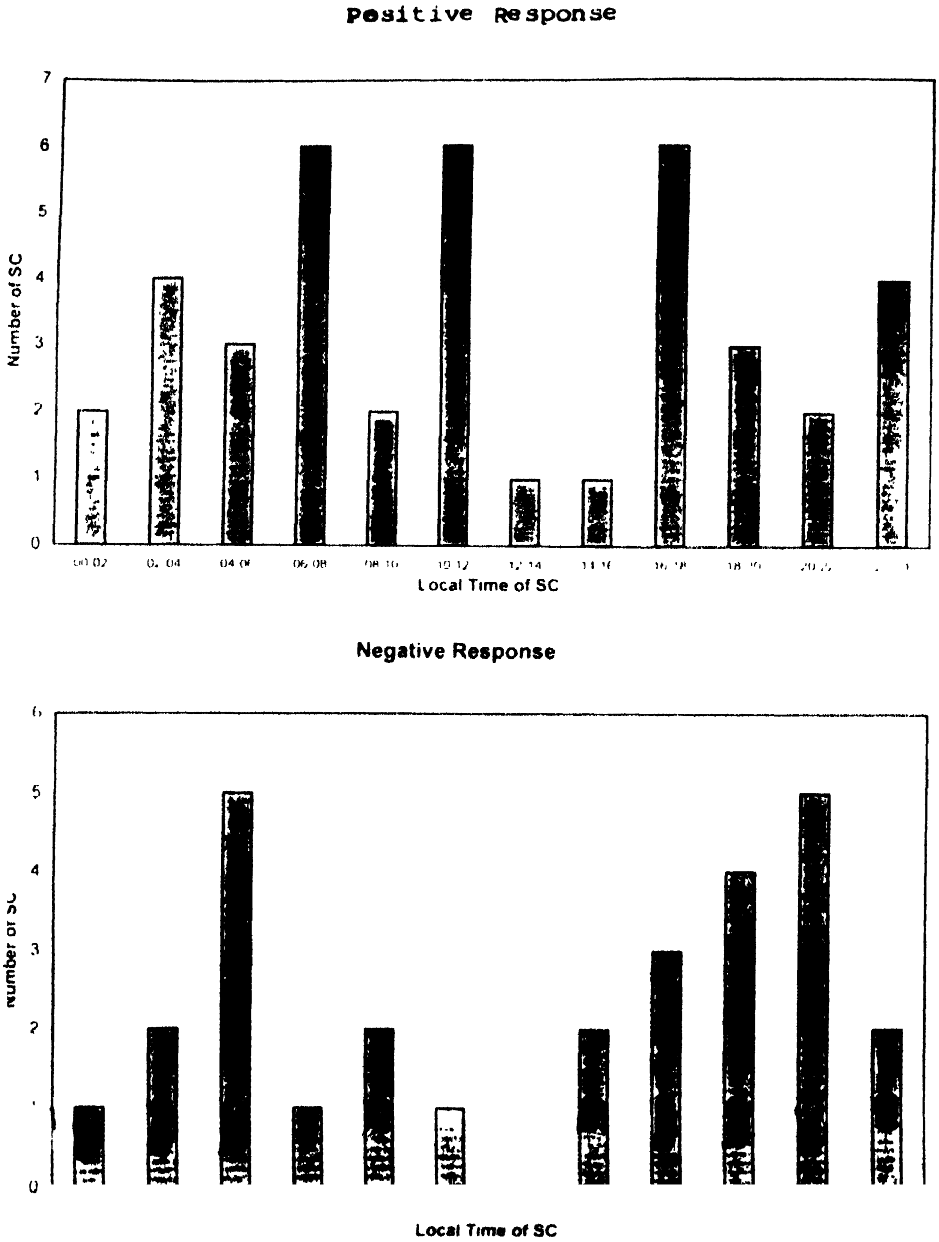
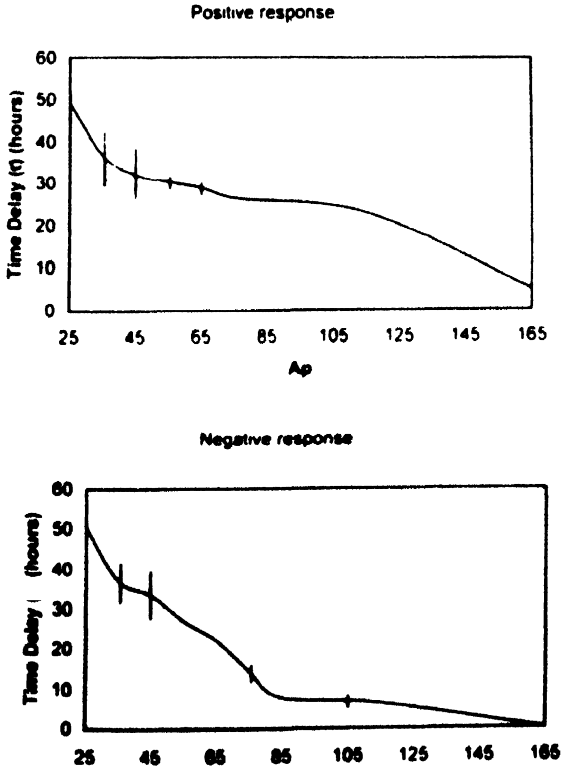


Figure 1. Local time distribution of the SCs which produced positive and negative ionospheric response.

Hourly values of TEC measured at Palehua [19.70°N, 157.2°W] using the GEOS 3 satellite during the period 1985–89 are used in the present study. The deviations in TEC (Δ TEC) on an hourly basis are obtained for each storm by subtracting the corresponding hourly values of the average of seven quiet days prior to the storm commencement from the values of TEC during the storm. If any two storms fall within ten days of each other, the mean of the seven days prior to the first storm was also used as the control curve for the second storm period. Here, the classification of ionospheric storm is based on the nature of the dominant deviation from control values. They are categorised as positive or negative according to whether the dominant deviation for a storm is on an increase or decrease. The relative deviations of TEC are not used to represent the strength of the storms in this study because, during night time, they may show abnormally high values due to the very low base line values. Hence absolute deviations of parameters are suitable to represent the strength of ionospheric storms [18].

The maximum positive or negative deviation from the corresponding average value is obtained for each storm which is considered as the strength of that storm. The time delay of ionospheric geomagnetic storm is taken as the time interval between the onset of SC and the time of maximum response. Maximum A_p values during the storm periods are used to represent the intensity of the geomagnetic storms.



2. Obt ... the time delay for ionospheric (A_p). Vertical bars

3. Results

Figure 1 shows the relationship between local time of positive and negative storm commencements and the number of corresponding SC storms. Out of the 68 storms considered here, 40 storms produced a positive response while 28, a negative response.

It is observed from Figure 1 that, the most probable local time (LT) of SCs which produced negative responses were around 21.00 hours. However, there is no probable local time of SCs which produced positive responses.

The dependence of time delay for maximum positive or negative response and the intensity of the storms as represented by A_p, are shown in Figure 2. For all the storms irrespective of their nature as positive or negative, the time delays are inversely proportional to the intensity of the storms. Also the slopes of the curves are steeper for lower values of A_p. This shows that the more intense the geomagnetic storm the quicker is the ionospheric response. Hence time delay (τ) has much significance because it indicates whether a storm is strong or weak.

Figure 3 gives the variation of time delay (τ) in accordance with the local time of SC. The vertical bars denote the standard deviations of the time delays from the mean time delays associated with the SCs occurring in local time bins of two hours. Figure 3 shows that the time delay for maximum positive response is shorter for daytime and longer for night time storms, where as it is just the opposite for maximum negative response. In fact, time delay signifies the fact that the

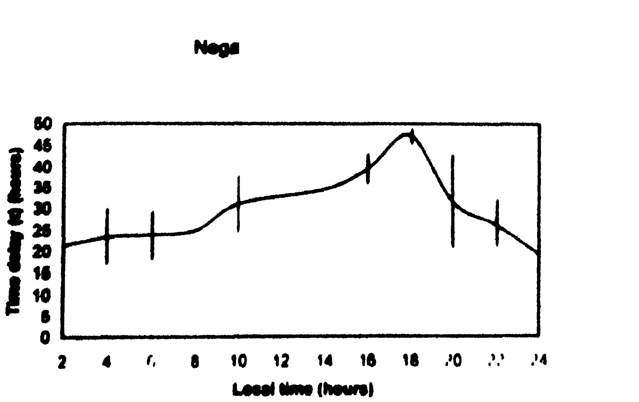


Figure 3. Dependence of the time delay for maximum positive and negative ... in TEC on local time.

quickness of ionospheric response to geomagnetic storm strongly depends on the strength and local time of sudden commencement (SC) of storm.

The strength of the ionospheric response depends on the intensity of geomagnetic storms (A_p). Figure 4 shows that, there exists a positive correlation between ΔTEC_{max} and

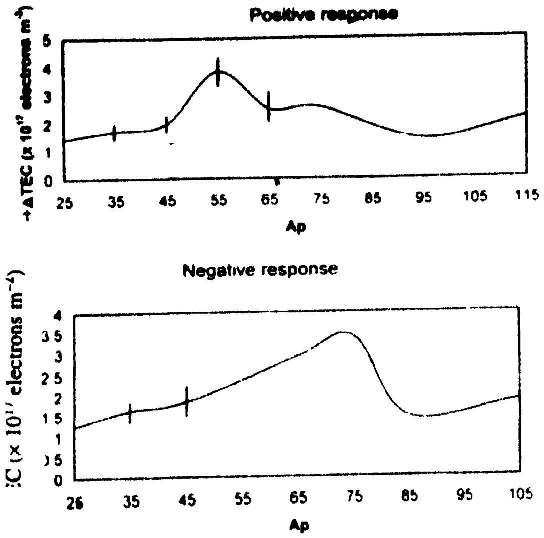


Figure 4. Dependence of the strength of positive and negative response in TEC on the intensity of geomagnetic storms (A_p).

A_p. But for very intense (positive and negative) storms there is a tendency for the peak response to decrease with an increase in A_p.

4. Discussion

The average of disturbed magnetic field around a cycle of constant latitude is referred as Dst(H) index. Storm time studies have been conducted for low latitude stations like Hawaii and found that the time response of the ionosphere depended on the local time of SC rather than the main phase onset or main phase of Dst(H) [19]. Also the typical storm effects at the low latitude station are an initial increase followed by a decrease. A case study on the seasonal dependence of ionospheric storms at a low latitude station using simultaneous TEC and Nmax data for 27 SC-type magnetic storms have been conducted earlier [20].

In another study, more than 60 SC-type geomagnetic storms are analysed by considering the TEC of Hawaii and Hamilton during the period 1968–72 [21]. It shows the dependence of ionospheric storms on local time of occurrence, intensity and time lag for peak response. The results of the present study are in general agreement with the findings of the above studies. In addition, this study shows that the strength of both negative storms and positive storms decreases with increase in A_p for very intense storms. However, previous study observed this behaviour exclusively for positive storms.

The behaviour of ionosphere during a magnetic storm is influenced by two opposing effects : one, by meridional neutral air winds which cause an increase in electron content due to transport process and the other by a local thermospheric temperature rise which causes a decrease in electron content. If wind effects dominate the local temperature effects, the electron content will tend to increase. If reverse is true, the content will tend to decrease and if both effects are equal and dominant, there will be neither increase nor decrease of electron content. For severe stroms both wind effects and temperature effects dominate appreciably which will diminish the peak response. This may be the possible reason for the tendency for the peak response to decrease with an increase in A_p, irrespective of the nature of the strom as positive or negative. Another disagreement with the previous observations is that the present study does not find the most probable local time of SCs which produced positive ionospheric response.

The possible processes which might contribute to magnetic storm associated ionospheric variations are :

(1) Electromagnetic drift associated with storm time electric field,

(2) Enhanced thermospheric circulation (waves and winds) generated by auroral zone heating during magnetic storms and the consequent increased loss rates,

(3) Change in atmospheric composition due to enriched thermospheric circulation and

(4) Compression of plasmasphere by the enhanced solar wind. Now, the effects produced by each of these processes can be discussed briefly.

Generally, the long duration positive storm effects are caused by changes in the large scale wind circulation. At low latitudes the electrodynamic $E \times B$ drift is very effective in transporting ionization in the ionosphere [22]. It is also known that at low latitudes atomic oxygen is enhanced by transport from higher latitudes and/or the upswelling in the auroral oval [23]. This combined with the upward lifting of ionized medium caused by the strom-time eastward electric fields and equatorward neutral air winds would give prolonged enhancements in electron density values and TEC [24,25].

As a result of the upper atmospheric heating at high latitudes, atmospheric circulations are generated near the turbopause in both hemispheres. Air thus moves up at high latitudes followed by an equatorward motion and moves down at low latitudes followed by a poleward motion. Thus, the density of atomic oxygen is enhanced at low latitude which results in positive phases of stroms. Another mechanism, important for short duration positive responses is the effect of wave or travelling atmospheric disturbances [TADs] [26]. An important feature is that they carry along equatorward winds of moderate magnitude. The enhancement due to TADs are small at mid and high latitudes compared to those at the low latitudes.

It is generally accepted that the negative phase of an ionospheic response is caused by an increase in the loss rate of O^+ brought about by a molecular enriched atmosphere. A large scale thermospheric circulation, driven by high latitude heating associated with geomagnetic stroms, is considered responsible for the molecular enriched atmosphere [27]. Enriched thermospheric circulation results in a net transport of atomic oxygen equatorward from high and mid latitudes, thus decreasing the O/N_2 and O/O_2 ratios. Depending on the extent of the circulation, the ratios may decrease even at low latitudes. Lower O/N_2 and O/O_2 ratios result in a higher recombination rate for the atomic oxygen ions at all levels and hence, lower ionization density values and total electron contents. The negative storm effect caused by the above process usually starts in the early morning and extends to several hours during continued magnetic activity [28].

Under quiet geomagnetic conditions, the Earth's plasmasphere extends to L ~4–5. During geomagnetic stroms, the plasmasphere is compressed, causing the mid-latitude trough to move to lower latitudes. This can also cause a drop in TEC at low-latitude.

A recent study observes that auroral ionisation increases the conductivity of the thermosphere and the conductivity combined with magnetospheric convection electric field produces Joule heating which is the dominant atmospheric energy source during a storm. It also illustrates the relationship between the currents driven by magnetospheric electric fields and those driven by the high latitude winds as modelled with National Centre for Atmospheric Research Thermosphere Ionosphere – Electrodynamics General Circulation Model [NCAR TIE-GCM]. Model calculations indicate that more than 90% of the electrical energy is converted in to heat [29].

Another study showed that storm time ion drifts at low latitudes result from a combination of prompt penetration of electric fields, and dynamo action of disturbed winds that reach the equatorial ionosphere a few hours after the onset of magnetic activity. The penetration of magnetospheric electric fields in this empirical model has good agreement with that modelled by the RICE convection model [30]. Ionospheric disturbances are often observed in the zonal rather than in the vertical electric field and consequently drastic modifications are observed in the F layer plasma drift, layer height and densities. It is important to understand the ionospheric response features that depend upon immediate past history of the magnetospheric-interplanetary disturbance conditions [31]. The observed ionospheric response to geomagnetic storms is due to the relative influence of above processes as a function of time. An elaborate theoretical model considering all the above processes would be required to account for all the observed storm time features.

5. Conclusions

1. The time delays associated with peak positive responses were short for day time SCs and long for night time SCs; where as opposite effects were seen for negative responses.
2. The time delays were inversely proportional to the intensities of geomagnetic stroms. The more intense the geomagnetic storm the quicker was the ionospheric response.
3. A positive correlation between the strength of ionospheric response and the intensity of geomagnetic storms was observed. However, the strength of both positive and negative storms decreased with increase in A_p for very severe storms.

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References

[1] J E Titheridge *Planet. Space Sci* **20** 353 (1972)

[2] K Davies, R B Fritz and T B Gray *J Geophys. Res* **81** 2825 (1976)

[3] O P N Calla *J. Inst Telecom. Engrs* **17** 160 (1971)

[4] E Brookner *J Franklin Inst* **280** 1 (1965)

[5] P B Rao, V Vijayakumar, K Krishnamurthy, B V Krishnamurthy and C Raghava Reddy *COSPAR Symposium Series* **8** 217 (1980)

[6] Y V Somayajulu and A B Ghosh *The Geophysical Use of Satellite Beacon Observations* ed M Mendillo (Boston University) p 669 (1976)

[7] J A Klobuchar, K N Iyer, H O Vats and R G Rastogi *Indian J Radio Space Phys.* **6** 159 (1977)

[8] Michael J Buonsanto *J Geophys Res* **100** 23857 (1995)

[9] J B Evans *J. Atmos Terr Phys* **35** 593 (1973)

[10] A R Jain, M R Deshpande, G Sethia, R G Rastogi, M Sing, H S Guram, A V Janve and R K Rai *Indian J Radio Space Phys* **7** 111 (1978)

[11] H Chandra, G D Vyas and S Sharma *Indian J Radio Space Phys* **26** 30 (1997)

[12] M Mendillo *Planet. Space Sci.* **21** 349 (1973)

[13] K N Iyer *Indian J Radio Space Phys.* **22** 277 (1993)

[14] P K Banerjee and S Bhattacharya *Indian J. Radio Space Phys* **26** 93 (1997)

[15] T J Fuller-Rowell, M V Codrescu, R G Roble and A D Richmond *AGU Geophysical Monograph* **98** 203 (1996)

[16] G W Prolss *AGU Geophysical Monograph* **98** 227 (1996)

[17] M A Abdu, J H A Sobral, P Richards, M Marta de Gonzalez, Y N Huang, B M Reddy, K Cheng, E P Szuszczewicz and I S Batista *J. Geophys. Res* **101** 26729 (1996)

[18] G W Prolss and Najita *J. Atmos. Terr. Phys.* **37** 635 (1975)

[19] U N Huang, K Najita, T H Reolofs and P C Yuen *J. Atmos Terr. Phys* **36** 9 (1974)

[20] S Basu, B K Guhathakurta and S Basu *Ann Geophys* **31** 497 (1975)

[21] N Balan and P B Rao *J. Atmos Terr. Phys.* **52** 269 (1990)

[22] D S V V D Prasad and Rama Rao *Indian J. Radio Space Phys* **22** 391 (1993)

[23] H Rishbeth, T J Fuller-Rowell and A S Rodger *Phys Scr.* **36** 327 (1987)

[24] C A Reddy, S Fukao, T Takani, M Yamamoto, T Tsuda, T Nakamura and S Kato *J. Geophys. Res.* **95** 21077 (1990)

[25] Sudhir Jain *Ann. Geophys* **13** 256 (1995)

[26] G W Prolss, L H Brace, H G Mayr, G R Carignan, T L Killeen and J R Klobuchar *J. Geophys. Res.* **96** 1275 (1991)

[27] H G Mayer and H Volland *J. Geophys. Res* **78** 2251 (1973)

[28] M J Buonsanto, J C Foster, A D Galasso, D P Sipler and J M Holt *J. Geophys Res.* **95** 21033 (1990)

[29] G Lu, A D Richmond, B A Emery and R G Roble *J Geophys Res* **100** 19643 (1995)

[30] B G Fejer and L Scherliess *Geophys. Res. Lett.* **22** 851 (1995)

[31] J H A Sobral, M A Abdu, W D Gonzalez, B T Tsurutani, I S Batista and A L Clua de Gonzalez *J. Geophys Res.* **102** 14305 (1997)